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Energy and Agriculture in the Haitian Economy: A Computable General Equilibrium Model

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ENERGY AND AGRICULTURE IN THE HAITIAN ECONOMY: A COMPUTABLE GENERAL EQUILIBRIUM MODEL

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ABSTRACT

This report documents a computable general equilibrium (CGE) model of the economy of Haiti, emphasizing energy use in agriculture. CGE models compare favorably with econometric models for developing countries in terms of their ability to take advantage of available data.

The model of Haiti contains ten production sectors: manufacturing, services, transportation, electricity, rice, coffee, sugar cane, sugar refining, general agriculture, and fuelwood and charcoal. All production functions use functional forms which permit factor substitution. Consumption is specified for three income categories of consumers and a government sector with a linear expenditure system (LES) of demand equations. The economy exports four categories of products and imports six. Balanced trade and capital accounts are required for equilibrium. Total sectoral allocations of land, labor and capital are constrained to equal the quantities of these inputs in the Haitian economy as of the early 1980s.

The model is reduced to its dual form so that it may be solved numerically in terms of only nine prices and one quantity. All other endogenous prices and quantities can be derived from the solution values of these ten variables. The equation system is solved with a variant of Powell's algorithm for simultaneous, nonlinear, algebraic equations; the series of subroutines used in the solution procedure have been implemented on an IBM AT with a math coprocessor chip, but can be used on the IBM PC or XT with some sacrifice in speed.

The model can be used to study the consequences of fiscal and trade policies and sectorally oriented productivity improvement policies. Guidance is offered regarding how to use the model to study economic growth and technological change. Limitations of the model are also pointed out as well as user strategies which can lessen or work around some of those limitations.

EXECUTIVE SUMMARY

This report documents a computable general equilibrium (CGE) model of the economy of Haiti. An introductory section discusses the benefits and limitations of CGE models as analytical aids to economic policy development and compares CGE models with econometric models of developing countries. CGE models are particularly useful for investigating the unintended consequences of economic policies as well as the desired effects. However, their categorization of products and industrial sectors is more highly aggregated than policy makers will want to use for final policy discussions. A CGE model may point to import tariffs on agricultural inputs as effective policy instruments for the government's purposes, but to decide exactly which products to tax exactly how much, policy makers will want to use other, more narrowly focused analytical tools. The data requirements of CGEs are more lenient than those of econometric models, and CGEs are better equipped to accommodate the structural changes which economic development entails. The structural changes involved in economic development often pose severe stability problems in the estimation and interpretation of coefficients in econometric models.

This CGE model developed for Haiti models agricultural activities and energy production and use in particular detail. Ten major production sectors in all are specified: rice, coffee, sugar cane, sugar refining, general agriculture, fuelwood and charcoal, electricity, manufacturing, transportation and services. The use of agricultural residues as fuels is modeled in the rice, sugar cane, sugar refining and general agricultural sectors. In the service sector, both traditional and modern energy uses are modeled with nested energy production functions. A flexible input-output structure is modeled with the use of intermediate inputs in production functions; the intermediate inputs include domestically made products and imports.

Consumption in the economy is modeled with Stone-Geary utility functions, from which are derived the linear expenditure system (LES) of demand equations. Theoretically consistent systems of LES demand equations are constructed for three categories of individual consumers and a government sector. The individual consumer categories are low, middle and high income groups, distinguished on the basis of their ownership of land and capital. Government income is derived from tariff and domestic tax revenues and from foreign grants.

The economy exports four categories of products -- coffee, refined sugar, general agricultural products and manufactures -- and six imports: petroleum, coal, food, manufactured consumption goods, "raw" materials used in the manufacturing (assembly) sector, and manufactured agricultural inputs (e.g., fertilizers). Equilibrium requires balance of the trade and capital (foreign grants) accounts.

All production functions in the model permit input employment decisions to be affected by relative factor prices. The nested energy

production function in the service sector is a Constant Elasticity of Substitution (CES) form, and all others are Cobb-Douglas forms.

The sums of the sectoral employments of labor, land and capital are constrained to add up to the quantities of those factors in the Haitian economy in the early 1980s. This requires a more robust solution algorithm but prevents the possibility of generating by default an unrealistically large or small population, land area or capital stock.

The model contains over 110 endogenous variables, but its dual structure is used to reduce the system which must be solved numerically to ten equations in nine prices and one quantity. All other endogenous prices and quantities can be derived from the solution values of these ten variables. The derivation of the dual solution is illustrated with the example of a simple, 2 commodity-2 input-2 consumer economy. Because the model of Haiti contains a number of additional complications, particularly export markets with infinitely elastic demand curves and simultaneity between the level of production and government expenditure, two additional substitutions used to derive the dual solution to the Haiti model are shown in detail.

The parameters of the model are assigned values on the basis of Haitian data, with occasional supplementation by data from other similar developing countries or by figures implied by theoretical restrictions on the Haitian data. A variant of Powell's method for solving system of nonlinear, algebraic equations is used to solve the ten-equation system. The entire solution procedure involves a series of subroutines which operate on the IBM AT with a math coprocessor chip, solving quite rapidly; the same subroutines can be used on the IBM PC or XT but at slower speeds.

Several limitations of the model are noted, as well as suggestions for using the model within those limitations. The two principal limitations of the model are its degree of aggregation -- only ten production sectors -- and the fact that it is a static, long run equilibrium model with savings and investment not modeled. However, these limitations, particularly the latter one, are less restrictive than may first appear. Economic growth and technological change can be simulated by sequentially incrementing the exogenous capital stock and labor force and interpreting part of the consumption of manufactured goods to be real savings to match the investment represented by the increment to the capital stock. Tariff and domestic tax policies can be studied by changing tariff and tax rate parameters; government spending policies can be addressed with parameters in the government demand equations; and deficit spending can be simulated by simultaneously altering the foreign grants variable. Numerous options are available to study the consequences of technological changes in production and energy use.

1. INTRODUCTION

1.1. OVERVIEW

This document describes a computable general equilibrium model of the economy of Haiti which incorporates production, consumption, foreign trade and income distribution. Production in Haiti is conceptualized as being conducted in particular sectors, e.g., manufacturing, services, etc., with activity in each sector employing particular quantities of a number of inputs -- labor, capital, land and various intermediate inputs -- in proportions governed by production functions. The output produced in each sector is either consumed locally or traded externally according to rules described by a series of demand equations for several categories of intermediate and final consumers. There is a circular flow of product and income such that the value of goods consumed is equal to the value of goods produced.

The equation system describing these economic interactions is specified with explicit functional forms. The values of the parameter and exogenous variables of the system are based on available data on Haiti with supplementation where necessary from observed relationships in other developing countries and from theoretical conditions. With these parameter values, the equation system can be solved numerically for equilibrium values of sectoral outputs, prices of outputs and inputs, and local consumption and trade in the various products.

The model has several features which particularly commend it. First, the sums of the sectoral employments of labor, land and capital are constrained to equal the total amounts of those inputs available to the Haitian economy. Thus, model solution is not assisted by an incidental generation of an unrealistically large or small labor force, capital stock or land area. Second, the explicit specification of land as a factor of production ensures that the model will generate something like the actual areal densities of economic activity found in Haiti. Third, all the production functions have functional forms which permit relative prices to affect methods of production, which a wide array of evidence from developing countries indicates is the case.

1.2. USES OF A COMPUTABLE GENERAL EQUILIBRIUM MODEL

All models rely on assumptions, abstractions and simplifications, and CGE models are no exceptions. As will become clear from the description of this particular general equilibrium model of Haiti's economy, a good deal of detail is sacrificed in an effort to gain insights about several major structural characteristics of the economy as well as a number of more specific insights about energy use in particular sectors. As CGE models go, this one of Haiti is not highly disaggregated, but the ability to disaggregate is restricted by the availability of (1) data to guide disaggregation and (2) modeling and computing resources, as well as by the desire for more detail.

CGE models should not be evaluated on the basis of a single solution. Instead, their usefulness should be judged by the flexibility they offer to explore the implications of a range of alternative scenarios and policy actions, among which no single solution represents "the answer." For instance, a good deal of uncertainty may exist about the value of some behavioral or technological parameter, and the parameter may appear to play a role in determining the effectiveness of a particular economic policy that is being contemplated. Possibly the value of the parameter may make little difference to the policy's effectiveness, possibly it may. The CGE model can be solved with several different values of the parameter in question to see how sensitive the policy is to it; comparison of several solutions will offer guidance.

A CGE model is constructed to answer a particular array of questions, which implies of course that no CGE model can answer all questions. A new model can be developed to address a desired array of questions, or an already existing model can be restructured to answer an additional or alternative set. However, the structure of general equilibrium thought in economics divides questions into two major categories: economically meaningful ones and those which must be restructured before they meaningfully address economic issues.

An example of the latter kind of question would be to ask what would happen if, say, the allotment of land to rice cultivation is altered by the government when, in fact, the allotment of land to rice cultivation is endogenously determined by the model. There are several approaches to reducing this problem. One is to restructure the question to ask what policy instruments the government has which can alter the allotment of land to rice which otherwise would result from the normal interactions of the economy, free or guided. Following this line of reasoning, parameters can be varied to represent policy actions to alter land in rice, and the solution can be examined for any unintended side effects of achieving the desired result, e.g., the economy starts importing bread and beans. Alternatively, the model could be restructured on the hypothesis that the government does indeed have absolute control over the amount of land allotted to rice production. Suppose that in fact the government does have such control. The question immediately follows whether the government controls anything else -- labor, capital and other produced inputs in rice, land in any other activities, prices of rice and the inputs used in rice cultivation. Assume that the answers to all these other questions are negative; the government controls only land used in rice. The CGE model can be redesigned to account for this factor, but its solution is unnecessary to predict a number of results of the government's policy of increasing land in rice: with demand unchanged, the price of rice falls and other inputs into rice production decrease unless rice production sufficiently dominates production in the country to affect wages and other factor prices; if the price of rice is by and large given to the economy by international market, the rice price will not fall, and production may remain about the same or even fall somewhat if other input prices rise. But, at any event, the CGE model can be restructured to answer the question although a general equilibrium formulation predicts beforehand that direct interposition in the economy to achieve specific

goals can have large side effects relative to the magnitude of the intended direct change.

The general rule about using general equilibrium models to address economic policy questions is simple, however. The policy choices that are contemplated by the user of the model must affect parameters of the model directly, and then the levels of endogenous variables indirectly. Desired goals and available means for achieving them must be distinguished clearly.

Returning to the issue of the level of detail in a CGE model, the specificity of the policy questions which can be addressed usefully by any particular model depends on the model's detail. A model with the level of detail of the current Haiti model may be able to yield confident answers regarding the effectiveness of raising import tariffs on, say, manufactured agricultural inputs to achieve a particular goal, but it will not indicate which of those goods' tariffs should be raised; it only tells where to aim a more detailed, possibly partial equilibrium, analysis. Once such an issue is targeted, it may be both possible and useful to disaggregate the relevant portion of the CGE model to obtain additional policy insights. Whether such a course is cost effective depends on the particular problem. But again, a general rule is that a CGE model will not be the only or last analytical tool used in planning the design and implementation of a specific economic policy. A CGE model can, however, highlight potential detrimental impacts of unintended side effects that can attend policy choices based on the sole use of more tightly focused, but partial, analytical techniques in planning economic policies.

A brief comparison of a CGE model with an econometric model may be useful. The data requirements of a CGE model will become evident as the model of Haiti is developed below, but data problems often are not as severe or as crippling to CGE use as they are to econometric models. An econometric model of a particular country needs a time series on each variable, which usually restricts the number of variables that can be specified and the precision with which they can be estimated statistically. If sufficient time series observations are available, the question of structural stability of the estimated relationships over the period of observation raises its head. Economic development is the process of massive and fundamental structural change in an economy, and there is a contradictory element in positing stable relationships over a time period long enough to provide a respectable set of time series data. The estimated relationships, if they are statistically significant, may be subject to serious identification problems which make their interpretation difficult or impossible.

Returning to data requirements of CGE models, multiple observations of a variable are always nice to have, but in their absence, a single observation will serve to calibrate a parameter. Often a set of parameters must obey certain theoretical restrictions or properties so that incomplete information will imply information about the values of the remaining parameters in the set, in a way that cannot be accommodated

by an econometric model. Additionally, if quantitative data on certain variables are simply unavailable for the country being modeled, qualitative information can be used to assign quantitative values to some parameters. Sometimes data from other countries can be useful in filling in gaps in available data from the country under study. The sensitivity of the model's solution to variations in these parameters can be examined quite easily: substitute different values and solve again. The ability of CGE modeling to use a number of approaches, ranging from the theoretically sophisticated to the frankly ad hoc, to fill in data gaps is useful, but the potential problem of large cumulative error must be faced. Econometric modeling, of course, faces similar problems with data from developing countries, but despite the greater flexibility of CGE modeling to get a solution, CGEs do not offer the possibility of modeling without data. However, the principal message is that CGEs face lesser data problems than do econometric models in developing country applications.

Many of the structural changes that occur during development can be built into a CGE model: consumption shifts with income increases, major reorderings of the relative sizes of economic sectors, increasing productivity of factors of production such as labor, even changes in demographic behavior. Altogether, CGE modeling is a viable competitor to econometric modeling, particularly in developing countries.

Section 2 describes the equations of the model, detailing the production structures used, the demand system, foreign trade and income distribution. Section 3 describes the reduction of the large equation system to one of a size whose solution can be obtained on a personal computer. Before embarking on the exposition of the present model, a brief summary of the literature on CGE modeling is offered.

1.3. THE LITERATURE OF CGE MODELING

Computable general equilibrium models are numerical applications of the two-sector general equilibrium models popularized in international trade theory in the 1950s and 1960s, particularly by James Meade and Harry Johnson (Shoven and Whalley, 1984, p. 1007). The ability to obtain numerical solutions permitted the expansion of sectoral detail so that current models often have between ten and twenty, and sometimes as many as thirty to forty, production sectors, and upwards of fifteen final demand categories. Some models have extensive input-output structures as well, so that they work with produced, intermediate inputs rather than with only capital and labor.

Two major expository treatments of CGE modeling are Dervis, de Melo, and Robinson (1982), which describes both linear models (linear programming and input-output models) and the nonlinear models which have become more prominent lately; and Shoven and Whalley (1984), which focuses on the application of the nonlinear CGE models to the analysis of tax and international trade policy issues. Ginsburgh and Waelbroeck (1981) focus on linear (activity analysis) CGE models and discuss the

linearization of nonlinear functions so that linear programming approaches can be applied to models with substitutability in production and consumption (pp 41-48). Dervis, de Melo and Robinson (1984) and Ginsburgh and Waelbroeck (1981) discuss a wide range of numerical solution approaches, although the former offers more evaluation of user experience. Unless otherwise noted, the CGE models mentioned below are of the nonlinear variety.

Economic development in general has been a popular target for CGE models. Kelley, Williamson, and Cheetham (1972) and Kelley and Williamson (1984) have used CGE models for theoretical studies of the convergence of a dualistic economic structure over time and the growth of urbanization in a developing economy, respectively. These studies use sets of parameter values obtained from empirical studies of a wide range of countries, and the results of the model simulations do not describe any one country but are intended to yield general insights about the process of economic development. Theories about development are probed by seeing how well numerical simulation of them replicates the patterns of economic growth and development actually experienced by a range of countries. A number of empirically-based CGE studies of policy options in specific developing countries have been undertaken; a very small sampling of these studies include analyses of trade policy in Turkey in Dervis, de Melo, and Robinson (1982, Part IV) and Dervis (1983); a general study of resource allocation in Egypt (McCarthy, 1983); tax policy in Mexico (Serra-Puche, 1984); and urbanization in India (Becker, Mills, and Williamson, 1986). More extensive citations to empirically-based policy analysis for developing countries with CGE models are in Dervis, de Melo, and Robinson (1982).

It is a short step from the study of economic development with CGE models to the study of economic history with them, particularly when economic history is studied as a process of economic development in previous times. Kelley and Williamson (1974) have studied economic growth and structural transformation in Meiji-period Japan with a CGE model, and Williamson has used a similar model to study developments in the United States economy between the Civil War and World War I. James (1985) has recently reviewed the use of CGE models in the study of economic history.

The analysis of contemporary tax and international trade policies with CGE models has been reviewed by Shoven and Whalley (1984). Whalley (1985) has studied multinational trade liberalization, and Ballard, Fullerton, Shoven, and Whalley have studied United States tax policy, with CGE models. Scarf and Shoven (1984) and Piggott and Whalley (1985) contain a number of article-length studies of tax and trade policies.

Numerical specification of parameter values is an issue of major concern in non-econometric simulation models such as CGEs. Useful discussions of this subject are in Mansur and Whalley (1985), Jorgenson (1985), and Kelley and Williamson (1984, Appendices B and C).

This review of CGE work has given only a flavor of the kinds of analyses conducted with CGE models. It has not aimed at comprehensiveness. The citations in Dervis, de Melo, and Robinson (1982), Shoven and Whalley (1984), and James (1985) offer more comprehensive coverage of both literature and issues.

2. A MODEL OF THE HAITIAN ECONOMY

This section describes the structure of the model, both verbally and in terms of equation specifications. First, the structure of production is described. Next the modeling of personal income distribution is explained. Once personal income distribution is known, the demand system can be developed. Both production and demand systems deal with internationally traded products, and the model is closed with specification of the foreign trade sector. The government sector derives part of its income from import and export tariffs, so its exposition is left to the last.

2.1 PRODUCTION

Ten major production sectors are modeled: manufacturing, transportation, electricity, fuelwood and charcoal, services, general agriculture, coffee production, rice production, sugar cane production and sugar refining. Several of these major production sectors entail some subsidiary processes which are formulated as production activities but are not independent activities. Each production sector is modeled with a production function which describes the transformation of diverse inputs into the particular output and governs the substitutability among the inputs. From the production functions, the profit-maximizing quantity of each input and level of output can be determined, contingent upon input and output prices.

All of the production activities employ what are called original, or primary, factors of production: labor, capital and land, although it is immediately conceded that capital in particular can be produced, land can in effect be produced by clearance and drainage or destroyed via erosion, and that labor can be both produced and enhanced, the latter by, e.g., education. They are original in the sense that their production is taken as given by prior events outside the model. We begin with a certain history of production of capital goods, land preparation and population growth. These are the primary income sources of the economy of Haiti and are the ultimate sources of income.

Each production activity also employs inputs which are themselves produced within the domain of the model or by unspecified producers in foreign countries. For instance, most of the activities employ transportation services for movement of inputs and outputs. Several of the agricultural activities employ manufactured inputs such as fertilizer, non-retained seeds, bags, etc., which may be produced by the local manufacturing sector or imported. Several of the sectors use inanimate energy sources: electricity, petroleum products, firewood and charcoal. Electricity and firewood/charcoal are in turn produced by combinations of original and intermediate, or produced, inputs. Thus the production sector has an input-output structure.

2.1.1. Manufacturing

We begin the sectoral description with the manufacturing sector. Diverse products and methods are involved in manufacturing in Haiti, and aggregation of them all into a single sector entails obvious sacrifices in detail. At the very least, a subdivision into traditional and modern sectors would be desirable, but model size considerations ultimately are responsible for the decision to model a single manufacturing sector. Some attempt is made to accommodate the diversity within the actual manufacturing sector by specifying an array of intermediate inputs into the entire sector, all of which would be unlikely to be employed in any single line of production.

Thus manufacturing sector production, Q_M, is specified as

$$Q_M = A_M \, L_M^{\alpha_1} \, K_M^{\alpha_2} \, N_M^{\alpha_3} \, E_M^{\alpha_4} \, Q_{TM}^{\alpha_5} \, I_M^{\alpha_6} \, , \tag{1}$$

where $\sum_{i=1}^{6} \alpha_i = 1.0$ for constant returns to scale, and A_M is a parameter reflecting the state of technology. Land, capital and labor are represented by L_M, K_M and N_M, where the subscript M denotes their employment in manufacturing. The variable E_M is energy used in manufacturing and is a composite of a number of energy sources which is specified in a functional form of its own for convenience:

$$E_M = A_{ME} \, Q_{EM}^{x_1} \, P_M^{x_2} \, Q_{WM}^{x_3} \, B_{SCM}^{x_4} \, , \tag{2}$$

where $\sum_{i=1}^{4} x_i = 1.0$, and A_{ME} is another technology parameter, Q_{EM} is (produced) wood and charcoal and B_{SCM} is sugar cane residues. Sugar cane is one intermediate input used in the manufacturing sector, and the use of residues as fuel is contemplated as a constant function of the raw cane used: $B_{SCM} = k_{SM} \, Q_{ASM}$, where Q_{ASM} is raw cane used as an intermediate input used in manufacturing, described further below. Clearly, modern processes using electricity and petroleum products may not use firewood and charcoal (although some might use combinations of all three), and cane residues probably would be used primarily if not exclusively by producers using cane as an intermediate input. To allow for the possibility of multiple uses, we have specified a nested energy-in-manufacturing production function with its own technology parameter. Firm level, and possibly even some industry level, experience in developed countries might lead to some concern that the elasticity of substitution between fuels, say coal and petroleum, might be infinite--a slight price differential would lead to immediate and complete switching of fuels -- and that equation (2) is consequently misspecified without the inclusion of some capital which limited the substitution possibilities (see the nested energy production functions for services,

below). However, for an economy-wide manufacturing sector specification such as we have in equation (1), a certain amount of very high, interfuel substitutability in some firms is compatible with a much lower, aggregate sectoral substitutability without the specification of capital in equation (2).

Intermediate inputs in manufacturing, I_M, are even more diverse. Three categories of intermediates are used: imported "raw materials," M_{RM}, which might range from unassembled television components to specialty steel; products of the general agricultural sector, Q_{AM}, which could include hides, fibers and any number of food products for further processing (other than rice, coffee and sugar cane); and raw sugar cane, Q_{SCM}, which is used for purposes other than sugar refining. Again, these inputs are conceptualized as a bundle of intermediates, using another nested production function:

$$I_M = A_{MI}\, M_{RM}^{x_5}\, Q_{AM}^{x_6}\, Q_{SCM}^{x_7}\ , \tag{3}$$

where $\sum_{i=5}^{7} x_i = 1.0$, and A_{MI} is the associated technology parameter.

Finally, the manufacturing sector uses services of the transportation sector for delivery of outputs to sale sites, some input deliveries, and transportation of materials and people during the production process.

Profit maximization requires that values of marginal product equal marginal factor cost for all inputs. From this condition, the manufacturing sector's demand for each input is determined. For example, for land,

$$r = p_M\, \alpha_1\, \frac{Q_M}{L_M}\ , \tag{4}$$

in which the marginal cost of land, or the land rent, r, is equated to the value of marginal product of land in manufacturing on the right hand side. Rearranging yields the manufacturing sector's demand for land:

$$L_M = p_M\, \alpha_1\, \frac{Q_M}{r}\ , \tag{5}$$

which has the form $L_M^D = f(p_M, Q_M, r)$, with the usual properties $f_{p_M} > 0$, $f_{Q_M} > 0$, $f_r < 0$, where the subscripts represent the partial derivatives of the function f. Each factor used in the manufacturing sector has a similar condition, yielding manufacturing's demand for it. The case of the sugar cane residues used as fuel is somewhat more complex because a nonmarket, or shadow, price must be derived from it. From the

first-order (profit maximizing) condition for B_{SM} and recognizing that $B_{SM} = k_{SM}Q_{ASM}$,

$$PBSM = PSC \frac{\alpha_4 \; x_4}{k_{SM} \; \alpha_6 \; x_7} \; . \tag{6}$$

Several of the inputs used in manufactures are taxed, and the tax rate affects the factor demand. For example, in the case of petroleum the tax-inclusive factor demand by manufactures is

$$P_M = p_M \; \alpha_4 \; x_2 \frac{Q_M}{p_p(1+t_1)} \; , \tag{7}$$

where t_1 is the import tariff on petroleum expressed as an ad valorem tax. The general form of the factor demand equations then is $F^D_{ij} = f(p_i, Q_i, p_j, t_{ij})$, where F^D_{ij} is sector i's demand for factor j, p_j is the price of factor j net of tax, which is equalized across all sectoral uses of factor j, and t_{ij} is the tax rate on factor j in sector i, with $f_t < 0$. The other taxed inputs used in manufacturing are imported raw materials, M_{RM}, with an import tariff rate of t_3; electricity, Q_{EM}, taxed at the rate t_8; domestic agricultural inputs, Q_{AM}, taxed at the rate t_9; and transportation services, taxed at the rate t_{10}.

The behavior of the manufacturing sector is described by the principal production function, the two nested production functions for energy and nontransport intermediate inputs, and derived demand equations for the eleven inputs. The other production sectors have similarly structured descriptions: principal production functions describing the technology of production; possibly nested production functions for certain combined intermediate inputs, also describing technology; and factor demand equations describing economic behavior. We turn now to a specific description of the general agricultural sector.

2.1.2. General Agriculture

Although rice, coffee and sugar cane are singled out for particular attention, the largely agricultural economy of Haiti produces many more agricultural products: several varieties of beans, corn, sorghum, animals vegetables, fiber crops, bananas, and a number of others. These are aggregated into the general agricultural sector with a single production function:

$$Q_A + B = A_A \; L_A^{\alpha_7} \; K_A^{\alpha_8} \; N_A^{\alpha_9} \; Q_B^{\alpha_{10}} \; I_A^{\alpha_{11}} \; Q_{TA}^{\alpha_{12}} \; , \tag{8}$$

where Q_A is agricultural output and B is raw agricultural wastes, A_A is the technology parameter, and $\sum_{i=7}^{12} \alpha_i = 1.0$ for constant returns to scale.

Q_B is agricultural wastes which are used as fuel in agriculture, but to be used as fuel, the raw wastes, B, must be collected and processed with labor and transportation. A separate production function describes this process:

$$Q_B = A_B \, B^{x_8} \, N_B^{x_9} \, Q_{TB}^{x_{10}} \, , \tag{9}$$

with $\sum_{i=8}^{10} x_i = 1.0$, and A_B a technology parameter. Raw wastes are a constant function of agricultural output: $B = k_A Q_A$.

Two categories of intermediates are used in agriculture, imported manufactured inputs--e.g., fertilizers--and local manufactured goods--e.g., containers of various sorts. They are combined in a nested production function for manufactured intermediates, although the nesting is not necessary:

$$I_A = A_{AI} \, M_{AA}^{x_{11}} \, Q_{MA}^{x_{12}} \, , \tag{10}$$

where $x_{11} + x_{12} = 1.0$, A_{AI} is the technology parameter, M_{AA} is imported manufactured inputs used in agriculture, and Q_{MA} is locally produced manufactures used in agriculture.

In the case of agriculture, joint production takes place, and the marginal productivity of factors must be evaluated in terms of both products, not just the marketed one. Accordingly, the factor demand functions have the form

$$F_{Aj}^{D} = p_A^{*} \frac{\alpha_k \, Q_A}{p_j(1+t_{ij})} \, , \tag{11}$$

where $p_A^{*} = p_A + k_A p_B = p_A[1 + \alpha_{10} \, x_8/(1 - \alpha_{10} \, x_8)]$, and p_A is the price of the agricultural product, Q_A.

The only taxed inputs general agriculture uses are imported intermediates, M_A, with an import tariff at the rate t_{16}, and locally produced manufactured goods which are taxed at the rate t_7.

The agricultural sector's behavior is described by the main production function, the two nested production functions, and the nine factor demand equations. We note that the activities we have chosen to group under general agriculture use no fuels other than agricultural wastes. Energy can be supplied by people or by animals, which are subsumed under the categories of labor and capital. Greater disaggregation of agriculture might find specification of a separate animal category of inputs useful.

2.1.3. Coffee

Coffee production employs land, labor, locally produced manufactured goods and transportation. Evidence indicates that Haitian coffee

production uses almost no capital equipment and no fuels. The production function is:

$$Q_C = A_C \, L_C^{\alpha_{13}} \, N_C^{\alpha_{14}} \, Q_{MC}^{\alpha_{15}} \, Q_{TC}^{\alpha_{16}} \, , \tag{12}$$

where $\sum_{i=13}^{16} \alpha_i = 1.0$, and A_C is the technology parameter. The coffee sector is modeled with the single production function and four factor demand equations. It may prove desirable to incorporate some fuel use, possibly wood and charcoal, for drying. Locally manufactured intermediates, Q_{MC}, and transportation services, Q_{TC}, are both taxed at the previously noted rates.

2.1.4. Rice

The rice production specification is more complex than that for coffee. Two fuels are used: petroleum for the small amount of irrigation pumping and rice hulls, which must be collected and processed. The rice production function is:

$$Q_R + B_R = A_R \, L_R^{\alpha_{17}} \, K_R^{\alpha_{18}} \, N_R^{\alpha_{19}} \, E_R^{\alpha_{20}} \, M_{AR}^{\alpha_{21}} \, Q_{TR}^{\alpha_{22}} \, , \tag{13}$$

where $\sum_{i=17}^{22} \alpha_i = 1.0$, A_R is the technology parameter, $B_R = k_R Q_R$ is unprocessed rice hulls, E_R is energy used in rice production and is a nested function itself, and M_{AR} is imported intermediate inputs. The nested energy production function is :

$$E_R = A_{ER} \, Q_{BR}^{x_{13}} \, P_R^{x_{14}} \, , \tag{14}$$

where $x_{13} + x_{14} = 1.0$, A_{ER} is the technology parameter and Q_{BR} is collected and processed rice hulls, described by:

$$Q_{BR} = A_{BR} \, B_R^{x_{15}} \, N_{BR}^{x_{16}} \, Q_{TBR}^{x_{17}} \, , \tag{15}$$

where $\sum_{i=15}^{17} x_i = 1.0$, and A_{BR} is the technology parameter.

As in general agriculture, joint production occurs, and factor pricing incorporates the values of both products. For instance, the value of labor's marginal product in rice cultivation is

$$w = p_R^* \, \alpha_{19} \, \frac{Q_R}{L_R} \, , \tag{16}$$

where w is the wage rate (equalized across all sectoral uses of labor, hence no subscript on w) and $p_R^* = p_R + k_R p_{BR} = p_R[1 + \alpha_{20}\, x_{13}\, x_{15}/(1-\alpha_{20}\, x_{13}\, x_{15})]$.

The taxed factors in rice cultivation are transport services and imported intermediates, M_{AR}, both taxed at the previously noted rates, and petroleum, assumed to be diesel and gasoline, with a gasoline tax, t_{17}, imposed in addition to the import tariff, t_1. Thus the demand for petroleum products in rice cultivation is

$$P_R = \frac{p_R^*\, \alpha_{20}\, x_{14}\, Q_R}{p_P(1+t_1)(1+t_{17})} \,. \tag{17}$$

The rice production sector is modeled with the main production function, two nested production functions and nine factor demand equations.

2.1.5. Sugar Cane

Like coffee production sugar cane production is specified as using neither energy nor capital equipment. Although clearly tools are used for cutting the cane, the cane cultivation, overall, uses very little capital. Capital and energy use associated with sugar cane production are reserved for specification in the sugar refining sector. The cane production function is:

$$Q_{SC} + B_{SC} = A_{SC}\, L_{SC}^{\alpha_{23}}\, N_{SC}^{\alpha_{24}}\, M_{ASC}^{\alpha_{25}}\, Q_{TSC}^{\alpha_{26}} \,, \tag{18}$$

where $\sum_{i=23}^{26} \alpha_i = 1.0$, A_{SC} is the technology parameter, $B_{SC} = k_{SC} Q_{SC}$ is not bagasse, which is associated with cane processing, but cane tops and bottoms, which are assumed to be used as fuel only in sugar refining which itself is in close proximity to cane fields.

Again, joint production takes place, and inputs in cane production are priced at the value of all cane products and byproducts. For example, sugar cane's demand for land is

$$L_{SC} = p_{SC}^*\, \alpha_{23}\, \frac{Q_{SC}}{r} \,, \tag{19}$$

but the definition of p_{SC}^* is deferred until the exposition of the sugar refining sector because some cane byproducts are used there as well as in the manufacturing sector.

Transportation services and imported intermediates used in cane cultivation are taxed at the previously noted rates. The sugar cane sector is modeled with the production function and four factor demand equations.

2.1.6. Sugar Refining

The sugar refining sector is small but is important as an export earner and as a potential producer of energy. It has an intricate production structure. The principal production function is:

$$Q_{SR} + B_{SR} = A_{SR}\, Q_{SCSR}^{\alpha_{27}}\, L_{SR}^{\alpha_{28}}\, K_{SR}^{\alpha_{29}}\, N_{SR}^{\alpha_{30}}\, E_{SR}^{\alpha_{31}}\, Q_{MSR}^{\alpha_{32}}\, Q_{TSR}^{\alpha_{33}}, \qquad (20)$$

where $\sum_{i=27}^{33} \alpha_i = 1.0$; A_{SR} is the technology parameter; $B_{SR} = k_{SR}Q_{SR}$ is bagasse, E_{SR} is energy composed of petroleum and two residue fuels, bagasse from the refining itself and cane cuttings from the fields, noted under the discussion of the cane sector; Q_{MSR} is local manufactured products used in refining; and Q_{TSR} is transportation services. The nested production function for energy is:

$$E_{SR} = A_{ESR}\, P_{SR}^{x_{18}}\, Q_{BSC}^{x_{19}}\, Q_{BSR}^{x_{20}}\ , \qquad (21)$$

where $\sum_{i=18}^{20} x_i = 1.0$, A_{ESR} is the technology parameter, and Q_{BSC} and Q_{BSR} are collected and processed cane cuttings and residues from cane production and sugar refining, each with its own production function:

$$Q_{BSC} = A_{BSC}\, B_{SC}^{x_{21}}\, N_{BSC}^{x_{22}}\, Q_{TBSC}^{x_{23}}\ , \qquad (22)$$

$$Q_{BSR} = A_{BSR}\, B_{SR}^{x_{24}}\, N_{BSR}^{x_{25}}\, Q_{TBSR}^{x_{26}}\ , \qquad (23)$$

where $\sum_{i=21}^{23} x_i = \sum_{i=24}^{26} x_i = 1.0$, and AB_{SC} and A_{BSR} are technology parameters.

Taxed inputs in sugar refining are locally produced manufactures and transportation, both taxed at the previously noted rates, and petroleum, which incurs both import and domestic taxes.

Joint production is again involved, and factor demands are priced at the value of both refined sugar and bagasse. For example, the demand for capital in sugar refining is

$$K_{SR} = p^*_{SR}\ \alpha_{29}\ \frac{Q_{SR}}{q}, \tag{24}$$

where q is the rental price of capital and $p^*_{SR} = p_{SR}[1 + \alpha_{31}\ x_{20}\ x_{24}/(1 - \alpha_{31}\ x_{20}\ x_{24})]$. The shadow price of the bagasse from the refining is $p_{BSR} = p^*_{SR}\ \alpha_{31}\ x_{20}\ x_{24}/k_{SR}$. Altogether, the sugar refining sector is modeled with the main production function, three nested production functions, and thirteen factor demand equations.

Returning to the shadow price of sugar cane, the model presently contains no mechanism to ensure that the full marginal productivities of cane will be equalized between its uses in the manufacturing and sugar refining sectors. In the manufacturing sector, the shadow value of cane is $p^*_{SCM} = p_{SC}(1 + \alpha_4\ x_4/\alpha_6\ x_7)$, and in sugar refining it is $p^*_{SCSR} = p_{SC}(1 + \alpha_{31}\ x_{19}\ x_{21}/\alpha_{27})$. The two will be equal only through fortuitous characteristics of technology. Full value factor pricing in cane production thus requires that $p^*_{SC} = p_{SC}[1 + (\alpha_{31}\ x_{19}\ x_{21}/\alpha_{27})Q_{SCSR}/Q_{SC} + (\alpha_4\ x_4/\alpha_6\ x_7)Q_{SCM}/Q_{SC}]$. However, we have employers in the manufacturing and sugar refining sectors purchase cane at the common price of p_{AS}, with the shadow values of byproducts administratively returned to factors in cane production, but we do not explicitly model the tax-subsidy arrangements necessary to produce this outcome.

2.1.7. Fuelwood and Charcoal

Fuelwood and charcoal are aggregated into a single delivered output. Its production function is:

$$Q_W = A_W\ L_W^{\alpha_{34}}\ K_W^{\alpha_{35}}\ N_W^{\alpha_{36}}\ E_W^{\alpha_{37}}\ Q_{TW}^{\alpha_{38}}\ , \tag{25}$$

where $\sum_{i=34}^{38} \alpha_i = 1.0$, A_W is a technology parameter, and $E_W = Q_{WW}$ is energy from raw fuelwood required for conversion of wood to charcoal. The sector is described by the production function and five factor demand equations. Only the transportation inputs are taxed.

2.1.8. Transportation

The transportation sector uses three inputs: capital, labor and petroleum:

$$Q_T = A_T\ K_T^{\alpha_{39}}\ N_T^{\alpha_{40}}\ P_T^{\alpha_{41}}\ , \tag{26}$$

where $\sum_{i=39}^{41} \alpha_i = 1.0$, and A_T is the technology parameter. The sector is modeled with the production function and three input demand equations. Petroleum inputs in the transportation sector are subject to both the import tariff and the domestic gasoline tax.

2.1.9. Electricity

The electricity sector includes both steam and hydro generated electric power. Its production function is:

$$Q_E = A_E \, K_E^{\alpha_{42}} \, N_E^{\alpha_{43}} \, E_E^{\alpha_{44}} \, Q_{TE}^{\alpha_{45}} \, , \tag{27}$$

where $\sum_{i=42}^{45} \alpha_i = 1.0$, A_E is a technology parameter, and E_E is a composite of petroleum and coal used in steam generation:

$$E_E = A_{EE} \, P_E^{x_{27}} \, C_E^{x_{28}} \, , \tag{28}$$

where $x_{27} + x_{28} = 1.0$, and A_{EE} is a technology parameter. Energy derived from hydro power is not explicitly modeled, although the capital used in hydroelectric generation could be considered included in K_E.

Import tariffs are imposed on both petroleum, at ad valorem rate t_1, and coal, at ad valorem rate t_2. The sector is modeled with the principal production function, the nested production function and five factor demand equations.

2.1.10. Services

The service sector is quite diverse, including activities such as laundries, hotels and restaurants, various personal and professional services, nonmechanized porterage, etc. Energy use is modeled in some detail for this sector, with special, energy-capital combinations providing energy from different fuels. The production function is:

$$Q_S = A_S \, L_S^{\alpha_{46}} \, N_S^{\alpha_{47}} \, K_S^{\alpha_{48}} \, E_S^{\alpha_{49}} \, , \tag{29}$$

where $\sum_{i=46}^{49} \alpha_i = 1.0$, A_S is the technology parameter, and E_S is a nested energy variable composed of traditional (wood and charcoal) and modern (electricity and coal) fuels, which require particular combinations of capital for their utilization. Previous composite energy specifications have imposed unitary elasticities of substitution between the energy types, with Cobb-Douglas production functions, but a Constant Elasticity of Substitution (CES) production function is used in service energy to

allow for nonunitary fuel substitutability as relative energy prices change. The CES production function for energy in services is:

$$E_S = A_{SE} \, [\Phi \, E_{ST}^{-\rho} + (1-\Phi) \, E_{SM}^{-\rho}]^{-1/\rho} \quad , \tag{30}$$

where A_{SE} is the technology parameter; Φ is a distribution parameter which acts much as the α_i parameters do in the Cobb-Douglas functions; E_{ST} and E_{SM} are traditional and modern energy, which have their own production functions; and ρ is the substitution parameter, such that $\rho = (\sigma - 1)/\sigma > -1$, where σ is the positively defined elasticity of substitution between E_{ST} and E_{SM}. Traditional energy is produced with fuelwood and charcoal and appropriate capital such as wood-burning stoves:

$$E_{ST} = A_{SET} \, K_{SET}^{x_{29}} \, Q_{WSET}^{x_{30}} \quad , \tag{31}$$

where A_{SET} is the technology parameter for traditional energy generation in services and $x_{29} + x_{30} = 1.0$. Modern energy combines electricity, projected coal use and appropriate capital:

$$E_{SM} = A_{SEM} \, K_{SEM}^{x_{31}} \, Q_{ESEM}^{x_{32}} \, C_{SEM}^{x_{33}} \quad , \tag{32}$$

where A_{SEM} is the technology parameter for modern energy provision in services and $\sum_{i=31}^{33} x_i = 1.0$. Thus, while there is unitary factor substitution between capital and the energy sources within each of the traditional and modern service energy systems, there can be a greater or lesser degree of substitutability between the traditional and modern systems themselves.

2.1.11. Summary of the Production Sector

Ten production sectors are specified with constant returns to scale Cobb-Douglas production functions. Some of the sectoral production functions contain nested production functions for groups of intermediate or energy inputs. Nonunitary factor substitutability is permitted between traditional and modern energy in the services sector. Inputs are paid by marginal productivity factor pricing. There are several instances of joint production in a sector, involving the byproduct generation of a residue which is subsequently processed and used as a fuel. Factors engaged in joint production are paid the full value of their marginal products, although explicit tax-subsidy arrangements to deliver the shadow value of residue fuels to factors producing them are not modeled.

2.2. PERSONAL INCOME DISTRIBUTION

The three original factors of production are labor, N, land, L and capital, K. Each is in fixed supply, and in equilibrium each must be fully employed. All land and capital are domestically owned by individuals in three income categories -- low, middle, and high -- so personal income is distinguishable from factor income. Personal income for an individual in income group k is:

$$y_k = w(1 - t_{12}) + \frac{\theta_{Lk}\ r(1-t_{13})L}{\theta_{Nk}\ N} + \frac{\theta_{Kk}\ q(1-t_{14})K}{\theta_{Nk}\ N}, \qquad (33)$$

where t_{12}, t_{13} and t_{14} are the tax rates on wage, land and capital income; θ_{Lk} and θ_{Kk} are the shares of land and capital owned by the entire income group k; and θ_{Nk} is the share of the labor force in income group k. Personal income distribution is determined by two factors: factor ownership, which is determined outside the model, and original factor prices which are determined, as are all other factor prices, by marginal productivity pricing, although the resulting marginal productivity factor prices are influenced, through product demands, by the exogenous factor ownership distribution.

2.3. DEMAND

2.3.1. Products and Markets in the Model

The products made by the various production sectors enter the final consumption of the Haitian population, are used as intermediate inputs in other local production sectors, or are sold overseas. Nine domestically produced sectoral outputs and two imported commodities enter into final consumption: manufactures, general agriculture, rice, coffee, refined sugar, fuelwood and charcoal, transportation, electricity, services, imported food (M_F), and imported manufactured consumption goods (M_{MC}). Sugar cane is entirely consumed by the production demands of local manufactures and sugar refining. Several commodities enter both intermediate and final consumption: manufactures, general agriculture, fuelwood and charcoal, transportation and electricity. Four locally produced commodities are sold internationally as well as locally: manufactures, general agricultural goods, coffee and refined sugar. Finally, four categories of strictly intermediate goods are imported: petroleum, coal, "raw" materials used in manufacturing and produced agricultural inputs. The final demand system is now developed.

2.3.2. The Final Demand System

The Stone-Geary Linear Expenditure System (LES) is used to determine final consumption demands for locally produced and imported products. The linear expenditure system is derived from the Stone-Geary utility function:

$$U = \sum_{i=1}^{m} \beta_i \log(q_i - \gamma_i) \ , \tag{34}$$

where U is an individual's utility, q_i is the individual's consumption of commodity i, and γ_i is some subsistence (or otherwise nondiscretionary) level of consumption of commodity i such that $q_i > \gamma_i$. The LES demand system derived from this utility function is:

$$q_{ik} = \gamma_{ik} + \frac{\beta_{ik}}{p_i(1+t_i)} [y_k - \sum_{i=1}^{m} \gamma_{ik} \, p_{ik}(1+t_i)] \ , \tag{35}$$

where subscript k refers to the individual's income group; β_{ik} is the expenditure share elasticity of group k for commodity i and $\sum_{i=1}^{m} \beta_{ik} = 1.0$; $p_i(1 + t_i)$ is commodity i's gross price; and the term in brackets is discretionary income. The more commonly recognized income elasticity of demand for commodity i, ϵ_i, is related to β_i by the relationship $\epsilon_i = \beta_i/s_i$, where s_i is commodity i's expenditure share.

2.3.3. Product Markets: Final and Locally Produced Intermediate Goods

In equilibrium, the supply of and demand for each good are equated: $Q_i^S = Q_i^D = Q_i$. For example, the demand for the manufacturing sector's output has the following structure:

$$Q_M^D = \sum_{k=1}^{4} Q_{Mk}^d + \sum_{j=1}^{3} Q_{Mj}^d + Q_{Mx} \ , \tag{36}$$

where $Q_{Mk} = \left\{\gamma_{Mk} + \frac{\beta_{Mk}}{p_M(1+t_i)}[y_k - \Sigma \, \gamma_{ik} \, p_i(1+t_i)]\right\} \theta_{Nk} \, N$

is the final consumption demand of income group k. Thus demand for local manufactures is composed of final demands by the three groups of individual final consumers; government's final demands, although government income is yet to be defined; intermediate demands by general agriculture (Q_{MA}), coffee (Q_{MC}) and sugar refining (Q_{MSR}); and exports, which in the case of local manufactures are determined residually. The intermediate demands for manufactures are:

$$\sum_{j=1}^{3} Q_{Mj}^d = Q_{MA}^d + Q_{MC}^d + Q_{MSR}^d \tag{37}$$

$$= \frac{p_A^* \alpha_{11} x_{12} Q_A}{p_M(1+t_7)} + \frac{p_C \alpha_{15} Q_C}{p_M(1+t_7)} + \frac{p_{SR}^* \alpha_{32} Q_{SR}}{p_M(1+t_7)} .$$

The supply of domestic manufactures, Q_M^S, is given by the manufacturing sector production function, and in equilibrium that output equals the sum of the final and derived demands. Haiti is assumed to face given world prices for its manufactures, p_M, so the adjustment of local supplies to the sum of local and foreign demands is accomplished by adjusting the quantities of inputs used in the manufacturing sector. Any quantity of local manufactures which is unsold locally at the price p_M (plus the tax) is exported. Thus manufactured exports are determined residually. Service sector output, in contrast to that of the manufacturing sector, is composed only of final demands:

$$Q_S^D = \sum_{k=1}^{4} \left\{ \gamma_{Sk} + \frac{\beta_{Sk}}{p_S(1+t_{11})} \left[y_k - \sum_{i=1}^{12} \gamma_{ik} p_i(1+t_i) \right] \right\} \theta_{Nk} N . \qquad (38)$$

The supply of services is determined by the service sector production function; both the price of services, p_S, and the quantities of inputs into the service sector adjust to equate the supply and the demand. Services, like other locally produced goods, have an upward sloping supply curve defined by their production function.

Haiti faces flat supply curves for its imported consumption goods, food and manufactured consumption goods. Both goods have LES demand equations which, summed first over individuals within each consumer group and then across the consumption groups, yield total demand. Supply conditions are defined by their exogenous prices, p_{MF} and p_{MMC}.

As noted above, the price of manufactures facing Haitian manufactures involved in export is fixed. The same is the case for refined sugar exports: p_{SR} is given by the world sugar market. It is assumed that Haitian exports of coffee and general agricultural products are sufficiently differentiated from competing commodities that they face downward sloping export demand curves which are functions of prices and foreign income. Demands for Q_{CX} and Q_{AX} are expressed with LES demand equations.

Strictly speaking, pure intermediate goods can be labelled inputs, but as in the cases of those goods which are used both in final and intermediate consumption, production decisions must be made regarding locally produced, pure intermediates. Sugar cane is the only pure intermediate good produced in the model. It is demanded only by the manufacturing and sugar refining sectors:

$$Q_{SC}^D = Q_{SCM}^d + Q_{SCSR}^d = \frac{p_M \alpha_6 x_7 Q_M}{p_{SC}} + \frac{p_{SR}^* \alpha_{27} Q_{SR}}{p_{SC}} . \qquad (39)$$

The supply is governed by the sugar cane production function, and both the sugar cane price, p_{SC}, and input quantities adjust to equate demand and supply.

2.3.4. Input Markets

Haiti faces flat supply curves for imported intermediate goods and vertical supply curves for the three original factors, land, labor and capital. Demands for all of these inputs are derived from the first-order conditions of the production functions. For an example of the imported intermediate, the total demand for petroleum is:

$$P^D = P_M^d + P_R^d + P_{SR}^d + P_T^d + P_E^d \tag{40}$$

$$= \frac{p_M\ \alpha_4\ x_2\ Q_M}{p_P(1+t_1)} + \frac{p_R^*\ \alpha_{20}\ x_{14}\ Q_R}{p_P(1+t_1)(1+t_{17})} + \frac{p_{SR}^*\ \alpha_{31}\ x_{18}\ Q_{SR}}{p_P(1+t_1)(1+t_{17})} +$$

$$\frac{p_T\ \alpha_{41}\ Q_t}{p_P(1+t_1)(1+t_{17})} + \frac{p_E\ \alpha_{44}\ x_{27}\ Q_E}{p_P(1+t_1)} .$$

The supply curve for petroleum is defined by its exogenously determined price p_P.

Supplies of the original factors are exogenous, and the factor prices and their allocations across the variously priced sectors adjust to equalize demand and supply. For example, in the case of capital,

$$K^S = K = K^D = K_M^d + K_A^d + K_R^d + K_{SR}^d + K_W^d + K_T^d + K_E^d + K_S^d \tag{41}$$

$$+ K_{SET}^d + K_{SEM}^d ,$$

where the form of the individual sectoral demand functions is $K_i^d = p_i\ \alpha_{iK}\ Q_i/q$ for the Cobb-Douglas production functions and $K_{SEi}^d = \frac{p_S\ \alpha_{49}\ \Phi_i\ x_{ki}\ Q_S}{q}\left[\frac{E_S}{A_{SEi}\ E_{Si}}\right]^{\rho}$ for the nested CES production functions in the service sector. For labor, the equilibrium condition is

$$N^S = N = N^D = \sum_{i=1}^{14} N_i^d , \tag{42}$$

and for land,

$$L^S = L = L^D = \sum_{i=1}^{8} L_i^d \ . \tag{43}$$

2.4. FOREIGN TRADE

To recapitulate earlier descriptions, Haitian exports are grouped into three categories: manufactures, general agricultural products, coffee, and refined sugar. Imports fall into six categories: raw materials used in manufacturing, intermediate goods used in agriculture, petroleum, coal, food and manufactured consumption goods. Additionally, the Haitian government is specified as receiving cash grants, G, from overseas governments and agencies. The cash may be used to purchase locally produced goods, but to convert the cash grants into an augmentation of real resources, the Haitian economy must import an additional value of goods equal to the value of the cash grants.

Equilibrium requires balanced trade, including the foreign cash grants. The trade balance is:

$$\begin{aligned} p_M Q_{MX} + p_A Q_{AX} + p_C Q_{CX} + p_{SR} Q_{SRX} + G = {} & p_{MR} M_R + p_{MA} M_A + p_{MF} M_F \\ & + p_{MMC} M_{MC} + p_P P + p_C C. \end{aligned} \tag{44}$$

2.5. THE GOVERNMENT SECTOR

The government is specified as receiving income from tax revenues and foreign grants and spending the income on the same array of domestic and imported goods that individuals consume, although in different proportions. LES demand functions for the government are specified. Government income is:

$$\begin{aligned} y_G = {} & t_1\, p_P\, P + t_2\, p_C\, C + t_3\, p_{MR}\, M_R + t_{16}\, p_{MA}\, M_A + \sum_{i=1}^{11} \sum_{j=1}^{3} t_i\, p_i\, Q_{ij}^d \\ & + t_7\, p_{M} \sum_{i=1}^{3} Q_{Mi}^d + t_8\, p_{E} \sum_{i=1}^{2} Q_{Ei}^d + t_{10}\, p_{T} \sum_{i=1}^{12} Q_{Ti}^d \\ & + t_{16}\, p_A\, Q_{AM}^d + t_{17}(1 + t_1)\, p_P\, P_T + t_{12}\, w\, N + t_{13}\, r\, L + t_{14}\, q\, K \\ & + t_{15}\, p_M\, Q_{MX} + t_{20}\, p_{Co}\, Q_{CX} + t_{21}\, p_{SR}\, Q_{SRX} + G. \end{aligned} \tag{45}$$

The first three terms are revenues from import tariffs. The term $\sum_{i=1}^{211} \sum_{j=1}^{3} t_i \, p_i \, Q_{ij}^{d}$ is the sum of local sales taxes; fuelwood and charcoal are untaxed, and government consumption incurs only import tariffs, not local sales taxes. The following five terms are revenues from taxes on intermediate inputs and the gasoline tax, and the subsequent three terms are income tax revenues. The terms with t_{15}, t_{20} and t_{21} are export tariff revenues, and the last term is foreign grants. This value of government income is used in the government demand equations.

3. SOLUTION

The solution procedure is essentially quite simple although the size and structure of the model complicate it in practice. Despite a large number of endogenous variables--upward of one hundred--the dual structure of the model can be used to solve the entire model by solving for only the small number of endogenous prices: p_W (wood and charcoal), p_E (electricity), p_T (transportation), p_S (services), p_A (general agriculture), p_R (rice), w (the wage rate), r (land rent) and q (capital rental). Because of the foreign trade structure of the model, one quantity must also be solved for; Q_{MX} is chosen.

The next section uses a two commodity-two factor-two consumer case to illustrate the use of the dual structure to solve a general equilibrium model. The present model involves two complications, however, its relatively simple input-output structure and the simultaneity of government income and government spending. The methods of dealing with these are presented in the following two sections.

3.1. DUAL SOLUTION

Let two goods, A and B, be produced according to homogeneous degree-one Cobb-Douglas production functions using land, L, and capital, K:

$$Q_A = A_A L_A^{\alpha_1} K_A^{\alpha_2} , \sum_{i=1}^{2} \alpha_i = 1.0 \tag{46}$$

$$Q_B = A_B L_B^{\alpha_3} K_B^{\alpha_4} , \sum_{i=3}^{4} \alpha_i = 1.0. \tag{47}$$

From Stone-Geary utility functions, consumption, C, is described by LES demand equations for two categories of consumer, land rent recipients (group 1) and capital rent recipients (group 2):

$$C_A^1 = \gamma_{A1} + \frac{\beta_{A1}}{p_A} (y_1 - p_A \gamma_{A1} - p_B \gamma_{B1}) \tag{48}$$

$$C_B^1 = \gamma_{B1} + \frac{\beta_{B1}}{p_B} (y_1 - p_A \gamma_{A1} - p_B \gamma_{B1}) \tag{49}$$

$$C_A^2 = \gamma_{A2} + \frac{\beta_{A2}}{p_A} (y_2 - p_A \gamma_{A2} - p_B \gamma_{B2}) \tag{50}$$

$$C_B^2 = \gamma_{B2} + \frac{\beta_{B2}}{p_B} (y_2 - p_A \gamma_{A2} - p_B \gamma_{B2}) , \tag{51}$$

where y_i are incomes of land and capital rent recipients.

Equilibrium factor employment is determined from the first-order conditions from the production functions:

$$r = p_A \alpha_1 \frac{Q_A}{L_A} \quad \text{or} \quad L_A = p_A \alpha_1 \frac{Q_A}{r} \tag{52}$$

$$q = p_A \alpha_2 \frac{Q_A}{K_A} \quad \text{or} \quad K_A = p_A \alpha_2 \frac{Q_A}{q} \tag{53}$$

in production of commodity A, and

$$r = p_B \alpha_3 \frac{Q_B}{L_B} \quad \text{or} \quad L_B = p_B \alpha_3 \frac{Q_B}{r} \tag{54}$$

$$q = p_B \alpha_4 \frac{Q_B}{K_B} \quad \text{or} \quad K_B = p_B \alpha_4 \frac{Q_B}{q} \quad , \tag{55}$$

for B, where r is land rent and q is capital rent. Full employment in the factor markets is required for equilibrium:

$$L_A + L_B = \bar{L} \tag{56}$$

$$K_A + K_B = \bar{K} \tag{57}$$

In the goods markets, equilibrium requires that production (supply) and consumption (demand) be equated:

$$Q_A = C_A^1 + C_A^2 \tag{58}$$

$$Q_B = C_B^1 + C_B^2 \ . \tag{59}$$

Equivalently, for commodity A,

$$A_A L_A^{\alpha_1} K_A^{\alpha_2} = C_A^1 + C_A^2 \ . \tag{60}$$

Substituting the expressions for labor and capital demanded in sector A derived from the first-order conditions (equations 52 and 53) yields:

$$A_A \left[p_A \alpha_1 \frac{Q_A}{r} \right]^{\alpha_1} \left[p_A \alpha_2 \frac{Q_A}{q} \right]^{\alpha_2} = C_A^1 + C_A^2 \ . \tag{61}$$

Recalling that $\sum_{i=1}^{2} = 1.0$,

$$A_A \; PA \; QA \left(\frac{\alpha_1}{r}\right)^{\alpha_1} \left(\frac{\alpha_2}{q}\right)^{\alpha_2} = C_A^1 + C_A^2 \; . \tag{62}$$

But $Q_A = C_A^1 + C_A^2$, and the last expression can be written as

$$p_A = \frac{1}{A_A} \left(\frac{r}{a_1}\right)^{\alpha_1} \left(\frac{q}{\alpha_2}\right)^{\alpha_2} , \tag{63}$$

which is commonly known as the cost function for commodity A, which expresses the cost of that good as a function of input prices, r and q, and technology characteristics, α_i and A_A.

Doing the same substitutions for commodity B yields its cost function:

$$p_B = \frac{1}{A_B} \left(\frac{r}{\alpha_3}\right)^{\alpha_3} \left(\frac{q}{\alpha_4}\right)^{\alpha_4} \; . \tag{64}$$

Now, substituting the first-order conditions for the sectoral factor allocations (equations 52 through 55) into the full employment conditions (equations 56 and 57), we obtain:

$$p_A \, \alpha_1 \frac{Q_A}{r} + p_B \, \alpha_3 \frac{Q_B}{r} = \bar{L} \tag{65}$$

and

$$p_A \, \alpha_2 \frac{Q_A}{q} + p_B \, \alpha_4 \frac{Q_B}{q} = \bar{K} \; . \tag{66}$$

Then, multiplying both sides by the appropriate factor price:

$$r \, \bar{L} = p_A \, \alpha_1 \, Q_A + p_B \, \alpha_3 \, Q_B = p_A \, \alpha_1 (C_A^1 + C_A^2) + p_B \, \alpha_3 (C_B^1 + C_B^2) \tag{67}$$

$$= p_A \, \alpha_1 \left[\gamma_{A1} + \frac{\beta_{A1}}{p_A} (y_1 - p_A \, \gamma_{A1} - p_B \, \gamma_{B1}) + \gamma_{A2} + \frac{\beta_{A2}}{p_A} (y_2 - p_A \, \gamma_{A2} - p_B \, \gamma_{B2}) \right]$$

$$+ p_B \, \alpha_3 \left[\gamma_{B1} + \frac{\beta_{A1}}{p_B} (y_1 - p_A \, \gamma_{A1} - p_B \, \gamma_{B1}) + \gamma_{B2} + \frac{\beta_{B2}}{p_B} (y_2 - p_A \, \gamma_{A2} - p_B \, \gamma_{B2}) \right],$$

and similarly for $q\bar{K}$.

These last two equations, for $r\bar{L}$ and $q\bar{K}$, and the two cost functions for goods A and B form a system of four equations in four unknowns, p_A, p_B, r and q. The equilibrium values p_A^*, p_B^*, r^* and q^* can be substituted into the earlier equations to solve for the equilibrium quantities of consumption, production and factor allocations: Q_A^*, Q_B^*, C_A^{1*}, C_B^{1*}, C_A^{2*}, C_B^{2*}, L_A^*, L_B^*, K_A^*, and K_B^*.

The model of Haiti's economy is larger and contains some additional interactions, but the solution procedure is identical. Cost functions are obtained for six of the locally produced commodities (the price of sugar cane as a pure intermediate is implied by the prices of manufactures and refined sugar, given technical coefficients in production; and one market, coffee, is omitted using Walras' Law; both implied prices can be calculated from equilibrium values of other prices). The input-output structure is substituted out, as is the simultaneity of government revenue and expenditure, in order to obtain expressions for commodity demands which can be substituted in the factor market equilibrium conditions, as is done in equation (67) of the 2x2x2 example.

3.2 SUBSTITUTING FOR THE INPUT-OUTPUT STRUCTURE

The input structure is: locally produced manufactures are used in general agriculture, coffee and sugar refining; general agricultural products are used in manufactures; and sugar cane is used in manufacturing and sugar refining. The last i-o structure is easily eliminated by recognizing that, from the first-order conditions, sugar cane can be expressed in terms of manufactures and refined sugar:

$$Q_{SCM} = \frac{P_M \, \alpha_6 \, x_7 \, Q_M}{P_{SC}} \tag{68}$$

and

$$Q_{SCSR} = \frac{P_{SR}^* \, \alpha_{27} \, Q_{SR}}{P_{SC}} \, . \tag{69}$$

The intermediate uses of general agricultural products and manufactures have the same structure:

$$Q_{AM} = \frac{P_M \, \alpha_6 \, x_6 \, Q_M}{P_A} = \frac{P_M \, \alpha_6 \, x_6}{P_A} \left[\sum_{j=1}^{3} Q_{Mj}^d + Q_{MG}^d + Q_{MX} + Q_{MA} + Q_{MC} + Q_{MS} \right] \tag{70}$$

$$Q_{MA} = \frac{P_A^* \alpha_{11} x_{12} Q_A}{P_M(1+t_7)} = \frac{P_A^* \alpha_{11} x_{12}}{P_M(1+t_7)} \left[\sum_{j=1}^{3} Q_{Aj}^d + Q_{AG}^d + Q_{AX}^d + Q_{AM}^d \right] \tag{71}$$

$$Q_{MC} = \frac{P_C \alpha_{15} Q_C}{P_M(1+t_7)} = \frac{P_C \alpha_{15}}{P_M(1+t_7)} \left[\sum_{j=1}^{3} Q_{Cj}^d + Q_{CG}^d + Q_{CX}^d \right] \tag{72}$$

$$Q_{MSR} = \frac{P_{SR}^* \alpha_{32} Q_{SR}}{P_M(1+t_7)} = \frac{P_{SR}^* \alpha_{32}}{P_M(1+t_7)} \left[\sum_{j=1}^{3} Q_{SRj}^d + Q_{SRG}^d + Q_{SRX} \right] . \tag{73}$$

This forms a system of four equations in four unknowns: Q_{AM}^*, Q_{MA}^*, Q_{MC}^* and Q_{MSR}^* can be solved in terms of parameters, endogenous prices and Q_{MX}, government income (y_G), and refined sugar exports (Q_{SRX}):

$$\begin{bmatrix} 1 & \frac{-P_M \alpha_6 x_6}{P_A} & \frac{-P_M \alpha_6 x_6}{P_A} & \frac{-P_M \alpha_6 x_6}{P_A} \\ \frac{-P_A \alpha_{11} x_{12}}{P_M(1+t_7)} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Q_{AM} \\ Q_{MA} \\ Q_{MC} \\ Q_{MSR} \end{bmatrix} =$$

$$\begin{bmatrix} \frac{P_M \alpha_6 x_6}{P_A} \left[\sum_{j=1}^{3} Q_{Mj}^d + Q_{MG}^d + Q_{MX} \right] \\ \frac{P_A^* \alpha_{11} x_{12}}{P_M(1+t_7)} \left[\sum_{j=1}^{3} Q_{Aj}^d + Q_{AG}^d + Q_{AX}^d \right] \\ \frac{P_C \alpha_{15}}{P_M(1+t_7)} \left[\sum_{j=1}^{3} Q_{Cj}^d + Q_{CG}^d + Q_{CX}^d \right] \\ \frac{P_{SR}^* \alpha_{32}}{P_M(1+t_7)} \left[\sum_{j=1}^{3} Q_{SRj} + Q_{SRG} + Q_{SRX} \right] \end{bmatrix} . \tag{74}$$

In the right-hand-side vector, the $\sum_{j=1}^{3} Q_{ij}^d$ terms are individual demands and can be expressed in terms of parameters and endogenous commodity and factor prices, the latter composing incomes. The Q_{iG}^d are government demands, which are composed of parameters, endogenous commodity prices and government income, y_G:

$$Q^{d}_{iG} = \gamma_{iG} + \frac{\beta_{iG}}{p_i} \left[y_G - \sum_{i=1}^{11} \gamma_{iG}\, p_i \right] , \tag{75}$$

in which y_G is easily separated. The four-equation system is solved easily by Cramer's rule, temporarily leaving y_G and Q_{SRX} as parameters. This system and the system containing y_G and Q_{SRX} are solved recursively, and we now turn to the solution of that other system.

3.3. SIMULTANEITY IN GOVERNMENT INCOME AND EXPENDITURE

Equation (45) defines government income as the sum of various tax revenues and foreign grants. However, the quantity of, say, petroleum demanded is a function of, among other commodities, the total demand for manufactures (recall Eq. 40). From Eq. (36), government consumption is one element of the total demand for manufactures, and consequently, the government income from petroleum revenues depends on government income which is partially composed of petroleum tariff revenues. All the components of government income which are revenues from taxes on intermediate inputs pose this problem, but a very simple substitution can reduce the problem completely, allowing government income to be expressed in terms of parameters and endogenous variables.

At the present stage of substitutions, the only variable on the right hand side of the government income expression which cannot be expressed in terms of parameters, endogenous variables and y_G is Q_{SRX}. Q_{SRX} is also the only variable in the trade balance, Eq. (44), which cannot be so expressed, although the intermediate inputs in the trade balance must yet be expressed as functions of government income. Consequently, Eqs. (44) and (45) are a 2-equation system in two unknowns, y_G and Q_{SRX}.

Equation (44) can be rearranged and expressed as

$$Q_{SRX} = \frac{\Psi + \Omega\, y_G + \Gamma\, Q_{SRX}}{p_{SR}}$$

or

$$Q_{SRX} = \frac{\Psi}{p_{SR}(1-\Gamma)} + \frac{\Omega}{p_{SR}(1-\Gamma)}\, y_G , \tag{76}$$

in which Ψ represents a series of terms already expressed in terms of parameters and endogenous variables, Ω is the set of parameters and endogenous variables which form the coefficient of y_G, and $\Gamma < 1.0$ is the set of parameters and endogenous variables which form the coefficient of Q_{SRX}.

Government income can be rearranged and expressed as

$$y_G = \Lambda + \xi y_G + \pi Q_{SRX}$$

or

$$y_G = \frac{\Lambda}{1-\xi} + \frac{\pi}{1-\xi} + Q_{SRX} , \tag{77}$$

where Λ is the set of terms which are expressed only in terms of parameters and endogenous variables, $\xi < 1.0$ is the set of parameters and endogenous variables which are multiplied by y_G, and π is the set of parameters and endogenous variables which are multiplied by Q_{SRX}. In matrix form which is solved by Cramer's rule, the system is:

$$\begin{bmatrix} 1 & \frac{-\Omega}{P_{SR}(1-\Gamma)} \\ \frac{-\pi}{1-\xi} & 1 \end{bmatrix} \begin{bmatrix} Q_{SRX} \\ y_G \end{bmatrix} = \begin{bmatrix} \frac{\Psi}{P_{SRX}(1-\Gamma)} \\ \frac{\Lambda}{1-\xi} \end{bmatrix} . \tag{78}$$

The reduced form solutions for Q_{SRX}^* and y_G^* from Eq. (78) are substituted into the reduced form solutions of the intermediate demands for manufactures and general agricultural products of Eq. (74). Additionally, the expression for y_G^* can be used in all government demand equations. These substitutions permit the expression of all commodity demands in terms of parameters and endogenous variables, as was shown to be necessary for the dual solution, in Eqs. (58) and (59), or in Eq. (67) where those results are inserted into the factor supply equation.

3.4. SOLUTION OF THE HAITI CGE MODEL

The final system of equations for the computable general equilibrium model of the Haitian economy contains seven cost functions and the three original factor supply equations. Table 1 lists each equation and the variable whose value it determines.

Values for the parameters of the model as well as start values of the endogenous variables (initial guesses of their solution values used to start the solution algorithm) were derived from various data sources from the World Bank and the International Monetary Fund. Where necessary, those data were supplemented with data on other developing countries and, occasionally, "stylized facts" of economic development, e.g., the average capital-output ratio, which was used to approximate a total capital stock, K.

Table 1. Equations and variables of the Haiti CGE model

Equation	Variable Determined
1. Wood and charcoal cost function	P_W - price of wood and charcoal
2. Electricity cost function	P_E - price of electricity
3. Transportation cost function	P_T - price of transportation services
4. Services cost function	P_S - price of service sector output
5. General agriculture cost function	P_A - price of general agricultural products
6. Rice production function	P_R - price of rice
7. Manufacturing production function	Q_{MX} - quantity of manufactured exports
8. Labor market equilibrium: $N^S = N^D = N$	w - wage rate
9. Land market equilibrium: $L^S = L^D = L$	r - land rent
10. Capital market equilibrium: $K^S = K^D = K$	q - capital rental

The ten-equation system is solved numerically with a variant of Powell's method (Powell, 1970) for solving systems of nonlinear algebraic equations, using values of parameters which, as noted above, are chosen to describe the technological and behavioral circumstances of the Haitian economy in the early 1980s. The solution algorithm is composed of a number of FORTRAN subroutines which operate on an IBM AT with a mathematical coprocessor chip. (See Dervis, de Melo, and Robinson, 1982, pp. 494-495 on the robustness of CGE solutions with a Powell algorithm.) The same set of subroutines runs, but at slower speeds, on the IBM PC AND XT with no, or only minor, changes.

4. CONCLUSIONS: LIMITATIONS AND USES OF THE MODEL

4.1. SAVINGS AND ECONOMIC GROWTH

The present model is a static, long-run equilibrium model. That is, it tells the effects of particular parametric changes on the economy once all adjustments are made. The single time period used in the model is not a particular calendar time but rather is the time required for the adjustments to be completed.

A two- or multi-period model may, but need not, specify differential adjustment speeds of various processes. Several problems appear in specifying adjustment speeds so that full adjustment in all activities need not coincide with the exogenously specified periodization of the model. First, data are a problem. Information on adjustment speeds are difficult to obtain even from data-rich advanced economies. Second, there is a trade-off between disaggregation and adjustment specification because of the data problem: the greater the disaggregation, the more pure guesses will have to be made about adjustment speeds. Third, differential adjustment speeds may artificially accentuate short-term fluctuations between periods.

A useful compromise between an instantaneous adjustment, long-run model and a lagged adjustment model would involve the specification of capital vintages, physical depreciation rates and investment in a multi-period model so that identification of the model's periodicity with calendar time can be made without assuming instantaneous adjustment of fixed capital stocks. This would require incorporation of saving in the model.

Presently, however, saving and investment are not modeled. Saving could be incorporated very simply as, say, a fixed fraction of income, or it could be done with greater attention to theoretical considerations by incorporating it into the consumer demand system using, say, the extended linear expenditure system (ELES).

Short term growth can be approximated with the model in its present form, however, simply by incrementing the parametric labor and capital stocks in different solutions. Capital stock growth would require no current sacrifice of consumption, although that problem could be partially avoided by assuming that part of local and/or imported manufactured goods are in fact investment goods which create the next period's capital stock replacements and/or increments. Concurrent technical change could be accommodated by altering the technology coefficients in the production functions. So, options are available to the user of the present model to study intertemporal growth scenarios with some measure of theoretical respectability.

4.2. ANALYSIS OF ECONOMIC ISSUES

As noted in Section 1, the specificity of the economic policies which a CGE model can analyze usefully depends on the disaggregation of the model. It also depends on the closeness with which the CGE model replicates the economy's relevant institutions--e.g., the actual tariffs (and quotas, if any), subsidies, local taxes, factor ownership patterns and decision operation rules of the state. Calibration of the present model has paid relatively close attention to tariffs and local taxes, but neither subsidies nor state ownership of productive resources and activities are modeled. With the present level of aggregation, many tariffs and local taxes are, of course, averages. These aggregations naturally reduce the correspondence between a particular tax or tariff rate t_i in the model and any actual tax or tariff rate.

Rather than emphasize only the limitations of the present model, it may be more useful to potential users to describe what kinds of parametric changes can be conducted to simulate policy actions. First, of course, are the tax and tariff rates. A wide array of taxes and tariffs are specified, and subsidies could actually be modeled by making a tax rate negative. Government spending policies can be altered by manipulating the expenditure share elasticities in the government's demand system, the β_{Gi}. Such spending policies actually could replicate deficit spending by simultaneously increasing the value of foreign grants, G.

Policies often are concerned with altering the technological circumstances of production, and the model offers several options for exploring technical changes. The A_i parameters in the production (and cost) functions shift the overall productivity of resources in a given line of production, and with the nesting of energy production functions within the main sectoral production functions, the consequences of some fairly specific productivity improvements can be explored. It is quite clear, however, that the labels given to the variables are more abstract than the specific items policy makers usually want to affect. For example, local officials might very well want to introduce more efficient wood and charcoal, or even coal briquette, stoves into a number of traditional service activities--laundries, restaurants, etc.--but the concept of energy-specific capital in the service sector (K_{SET} in the model) would [illegible] utterly foreign to them. However, an increase in the parameter A_{SF} [illegible] see equations 30 and 31) would simulate the effect of upgrading t[illegible]itional stoves and wood boilers in traditional establishments in the service sector. Consequences of energy conservation programs could be examined by adjusting the A_i parameters in nested energy production functions.

A minor revision in the model could place productivity parameters on each input in each activity, e.g., of the form $A_{Li}L_i$, $A_{Ki}K_i$ and $A_{Ni}N_i$, in place of L_i, K_i and N_i. Suppose some project were undertaken to improve land productivity in rice, rather than the earlier example of a direct increase in rice acreage. The new parameter A_{LR} would be increased, and

the effective amount of land in rice cultivation would be increased initially, although the new equilibrium L_R^* could go in either direction. One disadvantage of this method of modeling the impacts of resource-using government projects is that the project does not actually cost anything in the present model formulation. However, as an approximation for the impacts of projects which are thought to have high benefit-cost ratios, the approach may be worth considering.

The model also offers some opportunity to explore the effects of introducing new technologies in production. One method of doing this is to change the α_{ij} coefficients in the production functions (or the Φ parameters in the CES production function), which effectively alters the blueprints for combining inputs. In CES production functions the substitution parameter could be changed either by itself or in conjunction with a change in the Φ parameter, to represent the introduction of more flexible techniques in production. Of course, the reverse experiment could be conducted, in which a more productive, but less flexible, new technique is introduced.

One potential problem in analyzing the consequences of many technical changes is that policy makers may have little or no influence over the circumstances represented by many of these parameters. Income could certainly be boosted by increasing all the A_i productivity parameters, but if it were as easy as changing a tariff rate t_i, it would have been done long ago. However, study of the technology parameters is worth pursuing to gauge the magnitude, direction and extensiveness of the consequences of changes. Additionally, the government may have some indirect influence on some of the A_i parameters. For instance, the energy conservation project example noted above would have the effect of shifting an A_i; the relevant questionnaire is by how much and at what cost. The user of the model would do well to study the parameter shifts to see which policies that the government has available are effectively represented by particular parameter changes.

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